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Willow Creek
Dam, Willow Creek,
Montana, Madison
County, MT-22

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PHASE I INSPECTION REPORT
NATIONAL DAM SAFETY PROGRAM

WILLOW CREEK DAM
WILLOW CREEK, MONTANA
MADISON COUNTY
MT-22

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PREPARED FOR:

HONORABLE THOMAS L. JUDGE
GOVERNOR, STATE OF MONTANA

STATE OF MONTANA
(OWNER)

WILLOW CREEK WATER
USERS ASSOCIATION
(OPERATOR)

PREPARED BY:
CH2M HILL
BELLEVUE, WASHINGTON

MAY 1980

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ARMY CORPS OF ENGINEERS

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EXECUTIVE SUMMARY

Under contract with the Seattle District Corps of Engineers, and with representation from the Corps, the State of Montana Department of Natural Resources and Conservation, and the Willow Creek Water Users Association, CH2M HILL inspected Willow Creek Dam on May 23, 1979, under the authority of Public Law 92-367. The dam is located on Willow Creek in Madison County, about 4 miles east of Harrison and about 9 miles upstream of Willow Creek, Montana.

This report was compiled from information obtained during an onsite inspection, review of construction plans, and analysis of available hydrologic information. Findings were compared with engineering criteria that are currently accepted by most private and public agencies engaged in dam design, construction, and operation.

FINDINGS AND EVALUATION

Willow Creek Dam is owned by the State of Montana Department of Natural Resources and Conservation, is operated by the Willow Creek Water Users Association, and is used for storage of irrigation waters. The 105-foot-high earth and rock fill dam impounds 26,600 acre-feet of water at top of dam, elevation 4744.5 feet National Geodetic Vertical Datum (NGVD), previously mean Sea Level (MSL). On the basis of criteria in U.S. Army Corps of Engineers Recommended Guidelines for Safety Inspection of Dams (Ref. 1), the project is large in size. The dam is located such that its failure could endanger many lives and cause extensive property damage. Therefore, the project is classified as having a high (Category 1) downstream hazard potential. Inspection criteria (Ref. 1) recommend that the spillway design flood for a large-sized project with a high downstream hazard potential be the probable maximum flood (PMF). The PMF is the flood expected from the most severe combination of meteorologic and hydrologic conditions that are reasonably possible in the region.

An estimated PMF was developed for the 155-square-mile drainage basin. Refinement of this estimate may either increase or decrease the final flood characteristics. The PMF resulting from the 72-hour general storm has an estimated volume of 140,000 acre-feet. The routing of the PMF was started with the reservoir at spillway crest, elevation 4736 feet NGVD. The routing indicates that the dam is overtopped during the PMF when approximately 12 percent of the total flood volume enters the reservoir; consequently,

Willow Creek Dam's spillway is seriously inadequate. The rockfill zone on the downstream portion of the embankment would not fail with the initial overtopping. However, as overtopping flow increased, rock would be displaced with accompanying rapid erosion and breaching of the earthfill and, within a short time, complete failure of the dam. Such a failure could endanger many lives and cause extensive property damage.

On the basis of the field inspection and study of hydrologic and operational data, Willow Creek Dam does not conform to Corps guidelines with respect to discharge and/or storage capacities. Because the project cannot safely handle a flood having one-half of the PMF ordinates, leading to potential loss of life and property destruction, the project is considered unsafe until the recommended actions are accomplished. Urgent action is necessary to gain additional storage and/or outflow capacity while studies are underway to safely resolve the situation. A reliable downstream warning and evacuation plan is required to minimize the potential for loss of life from failure of Willow Creek Dam.

In our judgment, the embankment stability may conform with inspection guidelines; however, information to confirm this judgment is not available.

RECOMMENDATIONS

Develop, test, and immediately place in operation a downstream warning plan, for use in the event of possible dam overtopping or structural failure. Provide 24-hour surveillance of the project during peak runoff periods and develop an interim reservoir operation plan to minimize the risk until the project can be made safe. The jet pump used to dewater the low-level outlet gate tower must be repaired and maintained operational. Cavitation damage on or near the outlet butterfly valve must also be repaired, as required. Conduct more detailed hydrologic and hydraulic routing studies to better determine the downstream hazard and required spillway capacity. Gather information necessary to verify the existence and geometry of the sand and gravel zone downstream of the impervious embankment, and conduct an analysis of the filter system and embankment stability. Modify the project as indicated.

Richard L. Foster
Professional Engineer

PERTINENT DATA

1. GENERAL

Federal ID No.	MT-22
Owner	State of Montana
Operator	Willow Creek Water Users Association
Date Constructed	1938
Purpose	Irrigation, Recreation
Location	Sec. 35, T1S, R1W, Principal Meridian
County, State	Madison, Montana
Watershed	Willow Creek, a Jefferson River Tributary
Downstream Hazard Potential	Category 1 (High)
USGS Quadrangle	Norris

2. RESERVOIR

Surface Area at Spillway Crest	885 acres
Drainage Area	155 square miles
Storage at Spillway Crest, Elevation 4736 feet NGVD	18,000 acre-feet
Storage at Dam Crest, Elevation 4744.5 feet NGVD	26,600 acre-feet
Surcharge Storage	8,600 acre-feet
Reservoir water surface elevation at the time of the inspection	4736.4 feet NGVD

3. SPILLWAY

Type	Uncontrolled, concrete-lined, ogee
Width (at crest)	90 feet
Length	240 feet
Crest Elevation	4736 feet NGVD
Capacity with Reservoir at Dam Crest	8,300 c.f.s.

4. OUTLET WORKS

Control Tower	8-foot-diameter dry well
Conduit	60-inch horseshoe shaped; lined with reinforced concrete and cast iron
Conduit Length	362 feet
Valves	One 54-inch-diameter emergency gate valve
	One 54-inch-diameter operating butterfly valve
Maximum Capacity with Reservoir at Dam Crest	700 c.f.s.

5. DAM

Type	Earth, gravel, and rockfill
Length	453 feet
Crest Width	28 feet
Crest Elevation	4744.5 feet NGVD
Hydraulic Height (Crest to Toe)	105 feet
Upstream Slope	1 V on 3 H
Downstream Slope	1 V on 1.5 H

CHAPTER 1

BACKGROUND

1.1 INTRODUCTION

1.1.1 Authority and Scope

This report summarizes the Phase I inspection and evaluation of Willow Creek Dam, owned by the State of Montana.

The National Dam Inspection Act, Public Law 92-367 dated August 8, 1972, authorized the Secretary of the Army, through the Corps of Engineers, to conduct safety inspections of non-Federal dams throughout the United States. Pursuant to that authority, the Chief of Engineers issued "Recommended Guidelines for Safety Inspection of Dams" in Appendix D, Volume 1 of the U.S. Army Corps of Engineers' Report to the United States Congress on "National Program of Inspection of Dams" in May 1975.

The recommended guidelines were prepared with the help of engineers and scientists highly experienced in dam safety from many Federal and state agencies, professional engineering organizations and private engineering consulting firms. Consequently, the evaluation criteria presented in the guidelines represent the comprehensive consensus of the engineering community.

Where necessary the guidelines recommend a two-phased study procedure for investigating and evaluating existing dam conditions so deficiencies and hazardous conditions can be readily identified and corrected. The Phase I study is:

(1) A limited investigation to assess the general safety condition of the dam.

(2) Based upon an evaluation of the available data and a visual inspection.

(3) Performed to determine if any needed emergency measures and/or if additional studies, investigations and analyses are necessary or warranted.

(4) Not intended to include extensive explorations, analysis or to provide detailed alternative correction recommendations.

The Phase II investigation includes all additional studies necessary to evaluate the safety of the dam. Included in Phase II, as required, should be additional visual inspections, measurements, foundation exploration and testing,

material testing, hydraulic and hydrologic analyses and structural stability analyses.

The authority for the Corps of Engineers to participate in the inspection of non-federally owned dams is limited to Phase I investigations, with the exception of situations of extreme emergency. In these cases the Corps may proceed with Phase II studies but only to the extent needed to answer serious questions relating to dam safety that cannot be answered otherwise. The two phases of investigations outlined above are intended only to evaluate project safety and do not encompass in scope the engineering required to perform design or corrective modification work. Recommendations contained in this report may be for either Phase II safety analyses or detailed design study for corrective work.

The responsibility for implementation of these Phase I recommendations rests with the State of Montana. It should be noted that nothing contained in the National Dam Inspection Act, and no action or failure to act under this Act shall be construed (1) to create liability in the United States or its officers or employees for the recovery of damage caused by such action or failure to act, or (2) to relieve an owner or operator of a dam of the legal duties, obligations, or liabilities incident to the ownership or operation of the dam.

1.1.2 Purpose

The purpose of the inspection and evaluation is to identify conditions that threaten public safety, so that they may be corrected in a timely manner by non-Federal interests.

1.1.3 Inspection

The findings and recommendations in this report were based on visual inspection of the project, a detailed review of available plans and specifications, and design analyses. Inspection procedures and criteria were those established by the Recommended Guidelines for Safety Inspection of Dams (Ref. 1).

Personnel present during the May 23, 1979, inspection included:

Larry Tegg, Engineer, State of Montana Department of Natural Resources and Conservation

Tom Ferguson, Engineer, State of Montana Department of Natural Resources and Conservation

Jack Cooper, Willow Creek Water Users Association

Richard D. Eckerlin, Geologist, U.S. Army Corps of Engineers

CH2M HILL personnel who participated in the field inspection and contributed to this report are:

Miles C. Bubenik, Geotechnical Engineer, Team Leader

Jerry Jacksha, Geotechnical Engineer

Loren Bottorff, Hydrologist/Hydraulics Engineer

Mons Hoyrup, Structural Engineer

This report has been reviewed by the State of Montana Department of Natural Resources and Conservation and the Willow Creek Water Users Association. Their comments are included in the Appendix.

1.2 DESCRIPTION OF PROJECT

1.2.1 General

Willow Creek Reservoir and Dam are located on Willow Creek, a tributary of Jefferson River, in Madison County, Montana, approximately 9 miles south of the town of Willow Creek (see Plate 1). The dam is currently listed in the National Inventory of Dams, and its Federal identification number is MT-22. The 105-foot-high dam impounds 26,600 acre-feet at dam crest, elevation 4744.5 feet NGVD. Based on a visual reconnaissance and engineering judgment, approximately eight homes and extensive agricultural land could be affected by a sudden breach. On the basis of this information and in accordance with the recommended guidelines, the project size is classified as large, and the downstream hazard potential is high (Category 1).

Principal use of the 885-acre reservoir is for irrigation storage. Although the project is owned by the State of Montana, operation and maintenance is performed by the Willow Creek Water Users Association.

The 240-foot-long spillway channel is located on the left abutment (looking downstream), as shown on Plate 2. A 60-inch horseshoe-shaped outlet, with two 54-inch-diameter gates and gate controls, is used for irrigation releases.

1.2.2 Regional Geology and Seismicity

The geology and seismicity of the Willow Creek reservoir area are addressed in a memorandum by R.D. Eckerlin (Ref. 2). The following information is taken from the memorandum:

> Willow Creek Dam is on Willow Creek in the western part of the Three Forks Basin and within the northern Rocky Mountains physiographic province. Willow Creek Dam is in rolling country between the Tobacco Root Mountains to the west and the northern end of the Madison Range to the East. The Tobacco Root Mountains and the Madison Range rise as much as 6400 feet above Willow Creek Reservoir and adjacent valleys.
>
> Willow Creek Reservoir is floored with Tertiary and Quaternary sediments composed of detritus from the bordering mountains. The dam spans the upper end of a narrow gorge cut through metamorphic rocks of Precambrian age.
>
> Topographic expression in the area indicates that two north-west-striking regional lineaments, which may be faults, cross the reservoir and are spaced approximately 1-1/2 miles apart. The freshness of the topographic expression on the northernmost lineament is suggestive of Holocene age movement. The northeast slope of a terrace remnant in Sections 9, 10, and 14, T2S, R1E, alines very closely with this lineament. When the stability analysis of Willow Creek Dam is conducted, a thorough examination of these lineaments should be done. The Jefferson Canyon thrust fault, trending east and dipping 40°N, is located approximately 8 miles north to northwest from the dam. This segment of the thrust is on the trend of the buried Willow Creek Fault Zone, a major tectonic boundary since the Precambrian which trends east-west about 8 miles north of the site.
>
> The dam lies in a zone that is seismically active and it is estimated that the dam experienced a 0.2 g bedrock acceleration during the 1959 Hebgen Lake earthquake. The Inspection Guidelines' (Ref. 1) Seismic Zoning Map shows the site in Zone 3, which has a potential for major earthquake damage. Although the Zoning Map is based on a known distribution of damaging earthquakes, it does not necessarily reflect accurate or adequate seismic design parameters for this site.

1.2.3 Site Geology

The discussion of site geology is also taken from the R.D. Eckerlin memorandum (Ref. 2).

Willow Creek Dam is an earth dam founded on Precambrian metamorphic bedrock.

Both abutments are composed of gneiss and mafic sills which are concordant with the foliation of the gneiss. Two predominant joint sets occur, one set along the foliation striking east-west and dipping 50°N, and the other set striking approximately east-west and dipping at high angles to the south. An east-west thrust fault dipping 50°N, presumed to be of late Cretaceous age, projects underneath the dam. The thrust is exposed in an east-facing spillway rock cut about 50 feet upstream from the spillway crest (Photo 2).

The spillway is located on the left abutment and consists of a concrete-lined channel blasted through metamorphic bedrock.

The 5-foot-diameter outlet tunnel was blasted through metamorphic rock.

Tertiary and Quaternary deposits of various kinds are exposed in shoreline slopes around most of the reservoir periphery. These deposits include flood-plain sediments, alluvial fan materials, aeolian (windblown) silts, colluvial materials, reworked glacial outwash, and volcanic ash. The reservoir is roughly L-shaped, with the main body extending to the south and the secondary body extending to the west. The north shoreline along the west arm and the shoreline at the dam are composed of Precambrian metamorphic rocks. Shoreline slopes are nearly free of trees and are gently inclined into the reservoir. Landsliding does not appear to be a hazard; however, occasional minor shoreline sloughing does occur within areas that have thick deposits of silt. Wave erosion of the reservoir sides is locally present.

1.2.4 Design and Construction History

The Willow Creek project was designed from 1934 to 1936 by the State Water Conservation Board, Helena, Montana. Construction began in 1937 and was completed in 1938. Original drawings are on file with the State of Montana. A detailed set of construction as-built drawings and information on construction control testing are not available.

In 1944, a severe flood eroded the unlined spillway channel. Plans for the present spillway were developed by the State Water Conservation Board, and a new concrete spillway was constructed in 1944 and 1945.

CHAPTER 2

INSPECTION AND RECORDS EVALUATION

2.1 HYDRAULICS AND STRUCTURES

2.1.1 Spillway

The spillway for Willow Creek Dam is located in rock at the left abutment. The unlined approach channel to the uncontrolled concrete ogee crest is short and unobstructed; there is no log boom upstream of the spillway (Photo 3). The crest discharges to a concrete chute which ends with a flip bucket near the creek level.

The concrete crest is formed to an ogee shape of approximately 7-foot design head. The apex of the spillway crest is at elevation 4736 feet NGVD, 8.5 feet below the low point on the dam crest. Pipes are embedded along the apex of the spillway crest for the installation of flashboards; however, the flashboards were not at the site at the time of the site inspection. The spillway is 90 feet wide with two 18-inch-wide round-nosed bridge piers. Abutment headwalls, placed perpendicular to the direction of flow, are rounded with approximately a 2-foot radius. Downstream of the crest, the spillway chute narrows to a 50-foot width within a distance of approximately 90 feet (Plates 3 and 4). Spillway walls may be overtopped by wave action during high flows; however, the spillway is founded on rock and well removed from the dam. The chute continues for 80 feet and ends at a flip bucket with a 10-foot radius. The downstream channel contains much rock and is not eroding or backcutting.

Generally, the concrete appeared to be in good condition. Shrinkage cracks were narrow and fairly close together. Spillway walls showed very little differential deflection at expansion joints. The spillway floor had about 6 inches of smoothly flowing water over it, indicating no great irregularities on the surface.

The spillway rating was developed by using the weir head-discharge relationship with head dependent discharge coefficients varying from 3.19 to 4.01. The coefficients are appropriate for an ogee crest with a 7-foot design head. The maximum discharge capacity of the spillway, with the reservoir at the top of dam elevation 4744.5 feet NGVD, was estimated to be 8,300 c.f.s. The spillway rating curve is shown on Plate 5.

2.1.2 Outlet

The outlet works is located in the left abutment. The intake structure could not be inspected because of the reservoir level, but construction plans show it as a pair of converging wing walls covered by a trashrack. The concrete conduit is a 60-inch-diameter straight-legged horseshoe section (Plate 6) approximately 362 feet long, of which 154 feet is cut and cover beneath the embankment and 208 feet is lined tunnel (Photo 4). The conduit has a 0.7 percent slope.

A gate tower is located about 230 feet downstream of the intake structure, near the dam centerline. The control for the 54-inch-diameter emergency gate valve is located at the bottom of the tower, and control for the 54-inch-diameter operating pivot butterfly valve is located at the top of the tower (Plate 6). The gate tower is covered by a locked gatehouse. The jet pump that is used to dewater the tower was not operating properly and considerable water (6+ feet) was in the bottom of the tower. The portions of the gates beneath the water appear to be in good condition, but corrosion could develop if the high water level continues.

The conduit ends at the tunnel downstream portal (Photo 5). A concrete chute, with semicircular side slopes extends approximately 20 feet downstream of the portal. The concrete of this outlet structure contained some cracks and spalling. The downstream channel contains much rock and is not eroding or backcutting.

The operating valve was closed during the inspection and the conduit was entered from the downstream portal. The conduit contained minor cracking in various places. Calcium build up at the cracks was common (Photo 6). Some water was seeping through the construction joints. The seats on the operating valve were leaking, and it was not possible to get within 15 feet of the valve. Because of this leakage, inspection for damage was not made.

The rating for the outlet works was developed with both valves fully open. A Mannings "n" of 0.013 was used to estimate friction losses with the conduit flowing full. The maximum discharge capacity of the outlet works, with the reservoir at the top of dam, elevation 4744.5 feet NGVD, was estimated to be 700 c.f.s.

2.1.3 Freeboard

Routings indicate the dam will overtop during the PMF; therefore, freeboard does not exist with the recommended spillway design flood. The vertical distance between the

low point on the dam and the reservoir level at the time of the inspection was 8.1 feet; the reservoir was about 0.4 feet above the spillway crest. The crest of the dam varies about 1.8 feet in elevation over its 450-foot length. The fetch for wind-generated waves is about 1,000 feet and wave runup on the embankment is estimated to be about 1.5 feet. The operating freeboard for normal conditions is adequate to prevent overtopping the embankment by wind waves.

2.2 HYDROLOGY, CLIMATOLOGY, AND PHYSIOGRAPHY

2.2.1 General

The climate of the area is continental in nature characterized by warm summers and cold winters. A climatological station (elevation 5500 NGVD) is located within the basin at Pony; however, only 19 years of records are available. A climatological station is located at Norris, about 10 miles southeast of the center of the Willow Creek Dam drainage basin. Mean annual precipitation at the Norris station is 18.5 inches with 52 percent falling in April through July. Mean February precipitation is 0.65 inches and mean July precipitation is 3.36 inches. Mean annual precipitation on the Willow Creek Dam drainage basin is probably near 16 inches.

Mean annual temperature at Norris is 47 degrees Fahrenheit (F), mean January temperature is 25.9 degrees F and mean July temperature is 70.3 degrees F. Temperatures on the Willow Creek Dam drainage basin probably average about 5 degrees cooler than at Norris. Summer temperatures can exceed 100 degrees F and winter temperatures can dip well below 0 degrees F. Winters have few extended cold spells; periods of warm, windy "chinook" weather occur between cold spells.

The drainage basin area for Willow Creek Dam is 155 square miles. The basin elevations range from 4740 feet at the dam to 10,600 feet at Mount Jefferson on the western boundary. Approximately an 8-mile length of drainage divide at the southwestern side of the basin exceeds 10,000 feet NGVD. Willow Creek and Norwegian Creek are the main inflow streams to Willow Creek Reservoir. South Willow Creek begins at the southwestern portion of the basin at Granite Lake, elevation 8900 feet NGVD. The creek flows in a northeasterly direction for 13 miles at an average gradient of 275 feet per mile. The creek then flows another 8 miles at an average gradient of 70 feet per mile to Willow Creek Reservoir. This reach of stream is in a wide (1 to 2 miles) valley containing many drainage channels. About 35 percent of the basin is forested and 65 percent is open range land.

There are several small dams and reservoirs within the Willow Creek Dam drainage basin. Mason Lake Dam (MT-1272) is 9 feet high and impounds 100 acre-feet of water. Middle Hollow Top Dam (MT-836) is 10 feet high and impounds 95 acre-feet. Albro Lake Dam (MT-328) is 12 feet high and impounds 80 acre-feet. Bell Lake Dam (MT-834) is 20 feet high and impounds 450 acre-feet. Camp Creek Lake Dam (MT-1274) is 27 feet high and impounds 170 acre-feet. Cataract Creek Dam (MT-5) is 78 feet high and impounds 1,480 acre-feet. Norwegian Creek Dam (MT-1271) is 66 feet high and impounds 1,500 acre-feet.

2.2.2 Reservoir Storage and Spillway Discharge

The reservoir has a surface area of 885 acres and a storage of 18,000 acre-feet at spillway crest, elevation 4736 feet NGVD. Approximately 8,600 acre-feet of surcharge storage is available in the reservoir between the spillway crest and the dam crest. The spillway discharge with the reservoir at the dam crest is 8,300 c.f.s., about 690 acre-feet per hour.

2.2.3 Estimated Probable Maximum Flood

The inspection guidelines recommend that the spillway design flood for a project of this type be the full Probable Maximum Flood (PMF). The PMF is the flood expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. An estimate of the PMF was made during this dam safety analysis and was routed through the reservoir.

The procedure contained in U.S. Weather Bureau's Technical Paper 38 (Ref. 3) was used to compute the probable maximum precipitation (PMP). This storm, for the 155-square-mile basin, produces 9.5 inches in 6 hours and 13.9 inches in 24 hours. The 72-hour precipitation was estimated to be 16.5 inches.

Frozen ground and no infiltration losses were assumed during the entire flood. A base flow of 775 c.f.s. was used for the entire flood.

A triangular unit hydrograph for a 1-hour rainfall duration was developed for the 155-square-mile drainage basin by procedures outlined in Design of Small Dams (Ref. 4). A curvilinear fit of the triangular unit hydrograph was used. This unit hydrograph was developed for the total basin as if none of the several small reservoirs were present since the area tributary to the reservoirs is small. The PMP was applied to the unit hydrograph by means of the computer program, HEC-1 (Ref. 5). This estimate of the PMP produced

a flood with a peak flow of 194,000 c.f.s. and a volume of 140,000 acre-feet. Because the dam overtops at such a small percentage of the PMF (see paragraph 2.2.4), attempts to refine the flood by accounting for overbank storage in the wide valley along Willow Creek or for failure(s) of upstream dams were not justified.

2.2.4 Flood Routing

The PMF was routed through the reservoir by using the computer program HEC-1 (Ref. 5). The reservoir level was assumed to be at the spillway crest at the beginning of the PMF. The routing shows that the dam will be overtopped during the PMF when approximately 12 percent of the total flood volume enters the reservoir. Floods much smaller than the PMF could overtop and fail the dam.

2.3 GEOTECHNICAL EVALUATION

2.3.1 Dam Embankment

The 105-foot-high, curved-axis earth, gravel, and rockfill embankment is 453 feet long and has a crest width of 28 feet. The upper 10 feet of the upstream slope is 1 V on 2 H; below, it changes to 1 V on 3 H. The downstream slope is 1 V on 1.5 H. An as-built construction drawing (Plate 7) shows the slope between the upstream impervious zone and the downstream sand and gravel and rock zone is 1 V on 0.25 H and is inclined upstream. A sand and gravel zone is located downstream of the sandy silt impervious zone, as shown on Plate 7. The upstream sandy silt impervious zone is founded on bedrock. The specifications did not limit soil type by size or laboratory tests. The placement method specified 6-inch horizontal lifts, compacted with three passes of a toothed roller generating 1,150 pounds per tooth. The embankment materials, if overtopped by flood flows, would rapidly erode and fail the dam.

The sand and gravel zone shown on Plate 7 may extend throughout the entire height of the embankment. However, it is not shown in the original plans and is not mentioned in the specifications, and there is no information or description of this material. The compaction specified for rockfill was a compactive effort necessary to avoid excessive settlements and voids.

Embankment materials were obtained from spillway, tunnel, and cutoff excavations, as well as onsite quarries and borrow pits.

On the day of the inspection, the downstream slope was covered with elongated, angular rockfill and a sparse covering of brush (Photos 7 and 8). Rockfill was segregated; the longer pieces were at the toe, probably the result of dumping riprap from the crest. No erosion, irregularities, slumps or cracks were present on the dam crest or slopes.

A portion of the 60-inch outlet conduit upstream of the tunnel was constructed by cut and cover methods. The plans do not clearly indicate if the conduit was placed on rock throughout this section. Four concrete cutoff collars are shown under the cut and cover section of the conduit.

The upstream slope is adequately protected from erosion caused from wave attack by a 3-foot thickness of riprap and gravel bedding (Plate 7).

2.3.2 Foundation Conditions, Seepage, and Drainage

The left abutment of the dam is on metamorphic rock consisting of layers of mafic sills and gneiss. The right abutment is moderately sloping ground, consisting of metamorphic rock covered by several feet of sandy silt overburden. Available information does not indicate if the right abutment downstream of the impervious zone was stripped of overburden prior to embankment construction.

A detailed description of the foundation preparation is not available; however, a letter from the project construction engineer to the State of Montana (Ref. 6) indicates that the entire impervious earth zone was carried to bedrock.

Specifications required that the embankment preparation for the remaining foundation (downstream) consist of stripping unsuitable material, scarifying, and compacting the resulting surface to minimum depth of 8 inches. Because as-built details are not available, the actual foundation treatment procedures are unknown.

No seepage or erosion from past seepage was observed on the embankment or abutment contacts during the inspection, at which time the reservoir pool was at elevation 4736.4 feet NGVD. Seepage of about 5 gpm was flowing clear from a bedrock joint parallel to foliation located approximately 6 feet above the outlet tunnel portal. This seepage continued while the outlet gates were closed for tunnel inspection. This seepage through the left abutment rock is probably flowing along the rock foliations and is unrelated to embankment stability.

The dam embankment contains no known internal drains or piezometers.

2.3.3 Stability

Guidelines for dam safety inspections (Ref. 1) recommend that stability analyses be on file for all dams in the high hazard category, and that the safety factor for the steady state seepage condition be greater than 1.5. Based on a review of available information, it is our preliminary judgment that the Willow Creek embankment stability may conform with the Corps guidelines if the downstream portion of the dam is free draining, as indicated. However, because of the hazard potential, this conclusion should be verified by analyses that take into account potential seismic and static loading conditions, seepage and strength characteristics of the embankment, and dam foundation and abutments. Sufficient information is not currently available for such analyses.

2.4 PROJECT OPERATIONS AND MAINTENANCE

The facility is owned by the State of Montana Department of Natural Resources and Conservation (DNRC) and is operated by the Willow Creek Water Users Association. Information on operation and maintenance was obtained from a discussion with Mr. Roy Miller of the Willow Creek Water Users Association because a formal project operation and maintenance program for the dam does not exist.

2.4.1 Dam

Dam maintenance is performed as required. Mr. Miller indicated that in recent years, the spillway concrete was patched in places and open joints were cleaned and filled with tar. Cavitation damage at the butterfly valve is periodically repaired with epoxy steel. This damage may be due to insufficient air supply in the space downstream of the valve. In general, the project appeared to be well maintained. Brush growing on the downstream side of the embankment and the improper functioning of the jet pump are two areas lacking recent maintenance.

The State of Montana DNRC conducts annual inspections of the facility and makes appropriate recommendations for maintenance and repairs.

2.4.2 Reservoir

The dam is visited about twice a month by Mr. Miller. The low level outlet is shut for the winter as soon as freezing begins. Usually, the reservoir fills in the spring and the spillway begins to operate before releases are needed for irrigation. The outlet is operated as required during the irrigation season. Maximum releases through the outlet for

irrigation are approximately 150 c.f.s. The reservoir is typically drawn down about 20 feet below the spillway crest by the end of the irrigation season; this drawdown is approximately 12,000 acre-feet. Flashboards in the spillway are not commonly used, but they were used for a short time in the spring of 1975.

2.4.3 Warning System

There is no formal warning plan for use in the event of impending dam failure.

CHAPTER 3

FINDINGS AND RECOMMENDATIONS

3.1 FINDINGS

Visual inspection of the dam, supplemented by analysis of the project in terms of the recommended guidelines performance standards, resulted in the following findings.

3.1.1 Size, Hazard Classification, and Safety Evaluation

In accordance with inspection guidelines, Willow Creek Dam is classified large in size and, based on our visual inspection and judgment, it has a high downstream hazard potential. Therefore, the guideline's recommended spillway design flood (SDF) for this project is 100 percent of the PMF. Based on reconnaissance-level investigations, the project is incapable of handling a flood having one-half the PMF ordinates without overtopping and causing the dam to fail which, in our judgment, could seriously jeopardize life and property downstream. Under our criteria, Willow Creek Dam is considered unsafe until the recommended actions are completed.

3.1.2 Embankment Dam

A visual inspection of Willow Creek Dam revealed no longitudinal or transverse cracking, or any embankment, abutment contact, or toe seepage. Seepage was noticed in bedrock above the outlet tunnel portal.

The upstream and downstream slopes were uniform with no irregularities or slumps. Both contain a sparse covering of small brush. Riprap on the upstream slope adequately protects against erosion, and the normal freeboard is adequate to prevent wind-generated waves from overtopping the dam crest.

Based on the visual inspection, available project data, and engineering experience, it is our preliminary judgment that the embankment stability may conform to the recommended guidelines. However, because of the dam's size and hazard potential, this conclusion must be verified by thorough seepage and stability analyses based on static and seismic loading conditions. Currently, sufficient information is not available for such analyses. The limits and gradation of the downstream sand and gravel zones are not well known and should be investigated and confirmed.

3.1.3 Spillway and Reservoir Capacity

The reservoir has a surface area of 885 acres and a storage of 18,000 acre-feet at spillway crest, elevation 4736 feet NGVD. Approximately 8,600 acre-feet of surcharge storage is available in the reservoir between the spillway crest and the dam crest. The discharge of the spillway, with the reservoir at the dam crest, is 8,300 c.f.s.

There is no log boom to protect the spillway from being clogged by floating debris.

3.1.4 Outlet Works

The outlet works conduit contained minor cracking in various places. Calcium buildup at the cracks was common. Some water was seeping through the construction joints. The seats on the operating valve were leaking, and it was not possible to get within 15 feet of the valve. Because of this leakage, inspection within this area of the conduit could not be made. However, experience indicates that cavitation damage periodically occurs downstream of the butterfly valve.

3.1.5 Operation and Maintenance

The State of Montana DNRC conducts annual inspections of the facility and makes appropriate recommendations for maintenance and repairs. The Willow Creek Water Users Association is responsible for operation and maintenance. Mr. Miller indicated that the spillway concrete was patched in places, and open joints were cleaned and filled with tar. Cavitation damage that occurs at the butterfly valve is periodically repaired with epoxy steel. In general, the project appeared to be well maintained. Brush growing on the downstream side of the embankment and the improper functioning of the jet pump are two areas lacking recent maintenance. The outlet is operated as needed for irrigation and is shut for the winter as soon as freezing begins. There is no formal downstream warning system for use in the event of impending dam failure.

3.2 RECOMMENDATIONS

Due to storage between normal pool and dam crest, the present project provides a degree of flood protection to the downstream area. The intent of report recommendations is to maintain or improve project safety, if feasible, while preserving this existing flood protection.

1. Immediately develop, implement, and periodically test an emergency warning plan for use in the event of impending dam overtopping or structural failure.

2. Provide 24-hour surveillance of the project during peak runoff periods.

3. Develop an interim reservoir operation plan to minimize risk until the project can be made safe.

4. Repair and maintain operational the jet pump in the bottom of the gate tower.

5. Inspect the areas on and near the outlet works butterfly valve for cavitation damage and repair as required. If extensive repair is necessary, investigate and implement a permanent remedy.

6. Inspect the outlet tunnel upstream from the valves and repair, if required.

7. Construct a log boom to protect the spillway from floating debris.

8. Do not use flashboards in the spillway.

The above recommendations will not make the dam safe but will reduce risk to life and property while the following recommended actions are being taken:

9. Conduct more detailed hydrologic and hydraulic routing studies to better determine the downstream hazard and required spillway capacity.

10. Confirm the existence, geometry, and seepage characteristics of the downstream sand and gravel zone, and determine whether this material provides filter protection for the upstream sandy silt.

11. Conduct and place on file, stability and seepage analyses of the dam embankment. We recommend that these analyses be performed by a qualified geotechnical engineer and be based on: seismic and static loading conditions; insitu strength properties of the embankment, foundation, and abutment materials; and phreatic surface conditions. Determine the seismic loads based on a seismic assessment of the area, and evaluate the project's response to a seismic event. Establish the material strength properties by drilling and sampling with laboratory testing as appropriate, and determine the phreatic surface by installing and monitoring piezometers.

12. Modify the project as studies indicate.

13. Review tunnel design and determine if a need exists to reduce hydraulic pressure in the left abutment rock where seepage is exiting above the outlet tunnel.

14. Conduct periodic inspections of Willow Creek Dam at least once every 5 years by engineers experienced in dam design and construction. In addition, immediately inspect the dam if a moderate magnitude earthquake occurs near the project.

REFERENCES

1. U.S. Army Corps of Engineers, Office of the Chief of Engineers Report to the U.S. Congress, National Program of Inspection of Dams, Vol. 1, Appendix D, "Recommended Guidelines for Safety Inspection of Dams," Washington, D.C., Department of the Army, May 1975.

2. Richard D. Eckerlin, Seattle District, U.S. Army Corps of Engineers, Memorandum on Willow Creek Dam Inspection, June 22, 1979.

3. U.S. Weather Bureau, Technical Paper 38, Generalized Estimates of Probable Maximum Precipitation for the United States West of the 105th Meridian, Washington, D.C., 1960.

4. U.S. Bureau of Reclamation, "Design of Small Dams," 2nd Edition, 1974.

5. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, Davis, California, January 1973.

6. J.L. McLaughlin (Willow Creek Dam Contractor) Letter to State Water Conservation Board, December 3, 1937.

APPENDIX

DEPARTMENT OF NATURAL RESOURCES
AND CONSERVATION
WATER RESOURCES DIVISION

THOMAS L. JUDGE, GOVERNOR
32 SOUTH EWING

STATE OF MONTANA

(406) 449-2872
HELENA, MONTANA 59601

April 15, 1980

Ralph Morrison
Department of the Army
Seattle District, Corps of Engineers
P.O. Box C-3755
Seattle, Washington 98124

Dear Mr. Morrison:

The Department of Natural Resources and Conservation has reviewed the final draft report on Willow Creek Dam (MT-22). We concur with the findings and recommendations as set forth by CH_2M Hill in the report and feel that the report satisfies the criteria for the Phase I evaluation. Minor comments have been discussed with your staff and we understand that they will be included in the final report.

We sent copies of the final draft report to the Willow Creek Water Users Association for their review and we are enclosing a copy of their comments for inclusion in the final report.

Thank you for the opportunity to review and comment on the final draft report for this project.

Sincerely,

for Richard L. Bondy, P.E.
Chief, Engineering Bureau
(406) 449-2864

RB/GM/mb
Enclosure

RECEIVED

Willow Creek Water User's Assoc.
Mary A. Miller, Sec.
Box 194
Willow Creek, Mt. 59760
April 7, 1980

Lawrence H. Tegg
Dam Safety Eng.
Engineering Bureau
Helena, Mt. 59601

Dear Sir,

In reply to our conversation of April 1st. on the telephone. Our board of directors held a meeting on April 7, 1980. We feel the dam is very safe for the following reasons.

_ We feel this dam is earthquake tested. It went through one major earthquake and 2 minor quakes.

_ Dam is in solid rock and dam material is very good.

_ We have no breaks or leaks.

_ There is no debree on lake shores to require a log boom across spillway.

_Spillway is large and in good shape. No one has ever seen over 14 inches of water go over the spillway in 43 years. We feel in this time we would have had as much flooding as we will ever see

_ Our soils above the dam take moisture readily and up to 50% of the run off would not reach the lake.

Due to the economy and the lack of funds in our water association, we do not feel these findings are necessary at this time. We do feel that the dam should be inspected yearly. We also feel that during a period of heavy rains, this dam should be monitured.

Sincerely,
Pres. Jack L Cooper
V. Pres. Robert C. Rice
Director Russell G. Anderson
Director Stacy N. Bottleman
Director. LeRoy Miller

Photo 1 Dam and Reservoir

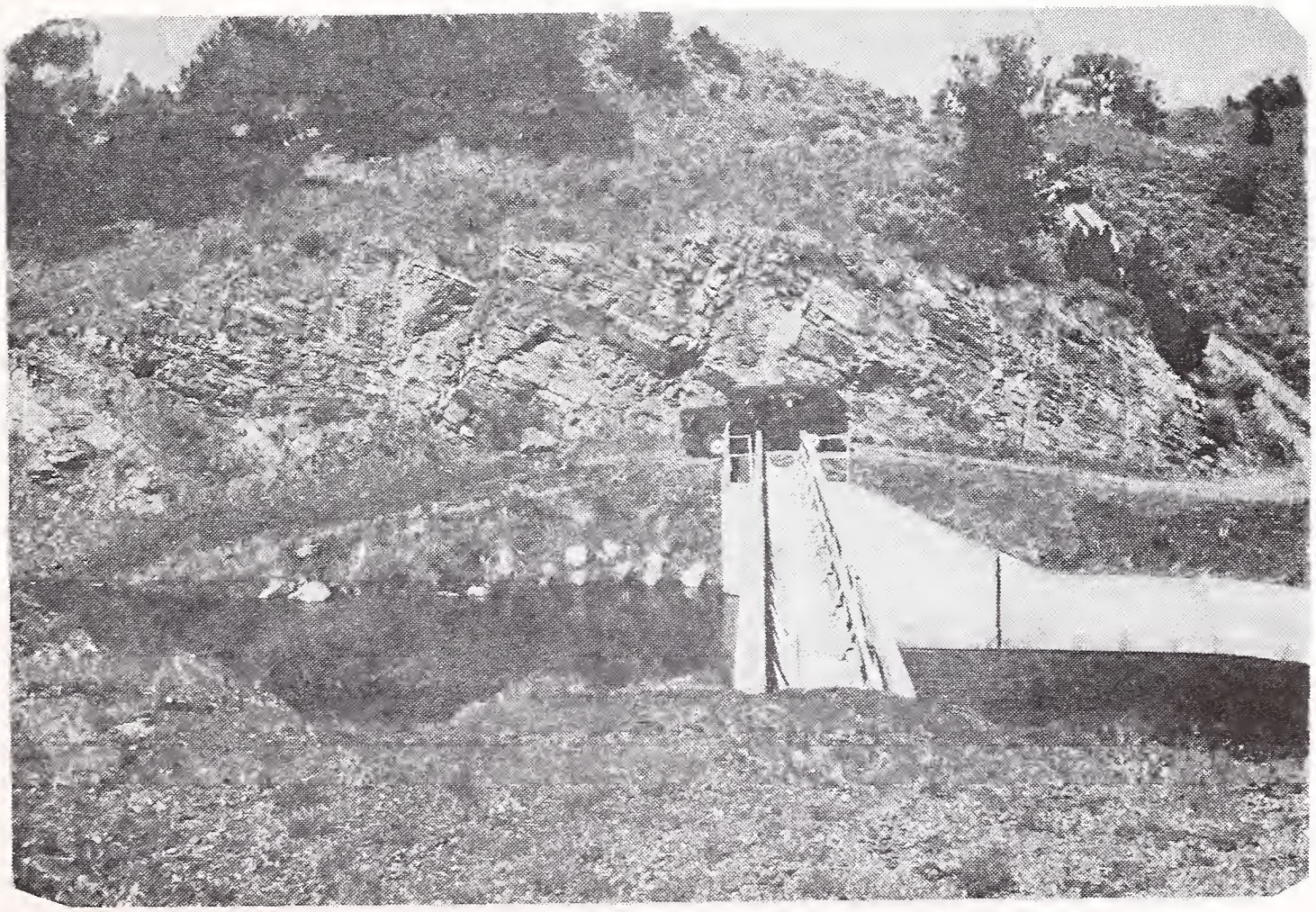


Photo 2 Exposed Rock Cut Left Side of Spillway

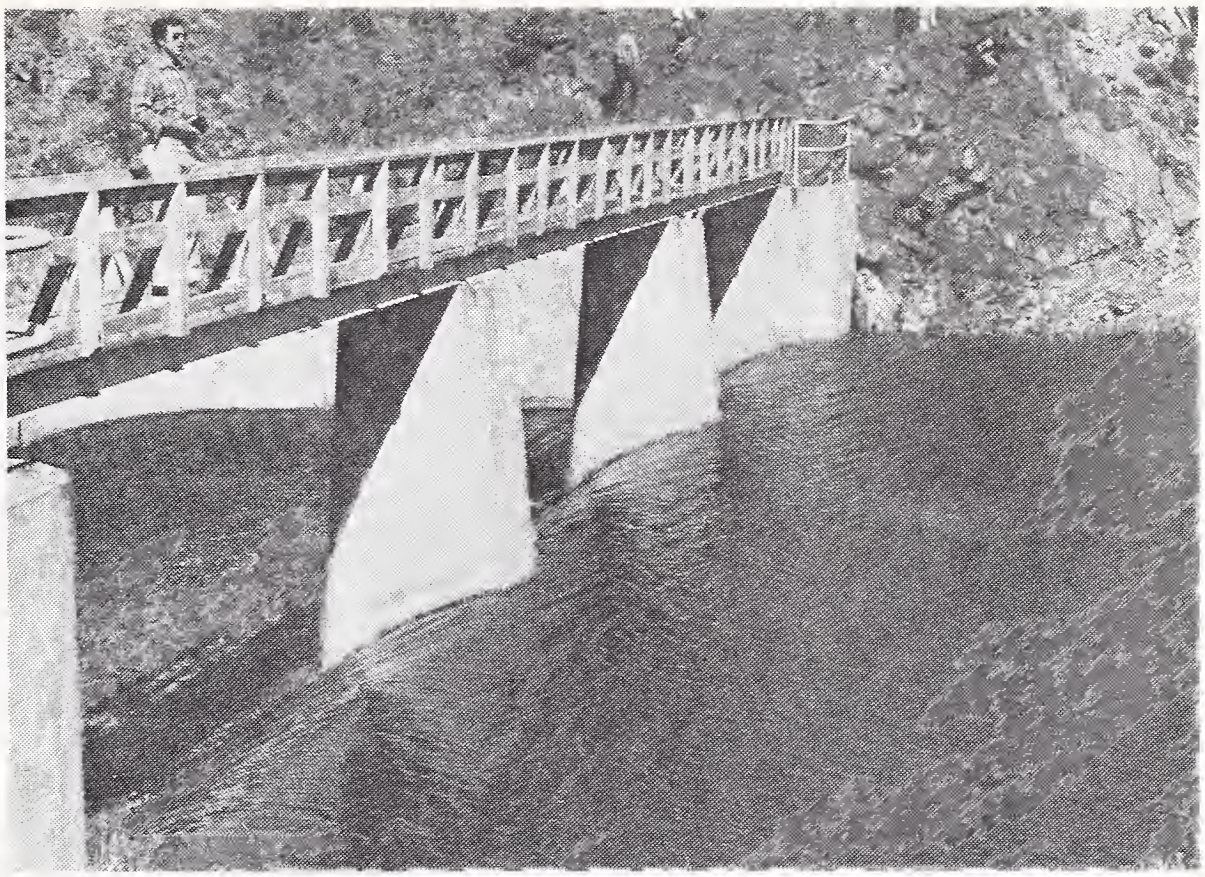


Photo 3 Spillway Crest

Photo 4 Outlet Tunnel Downstream of Tower

Photo 5 Tunnel Portal

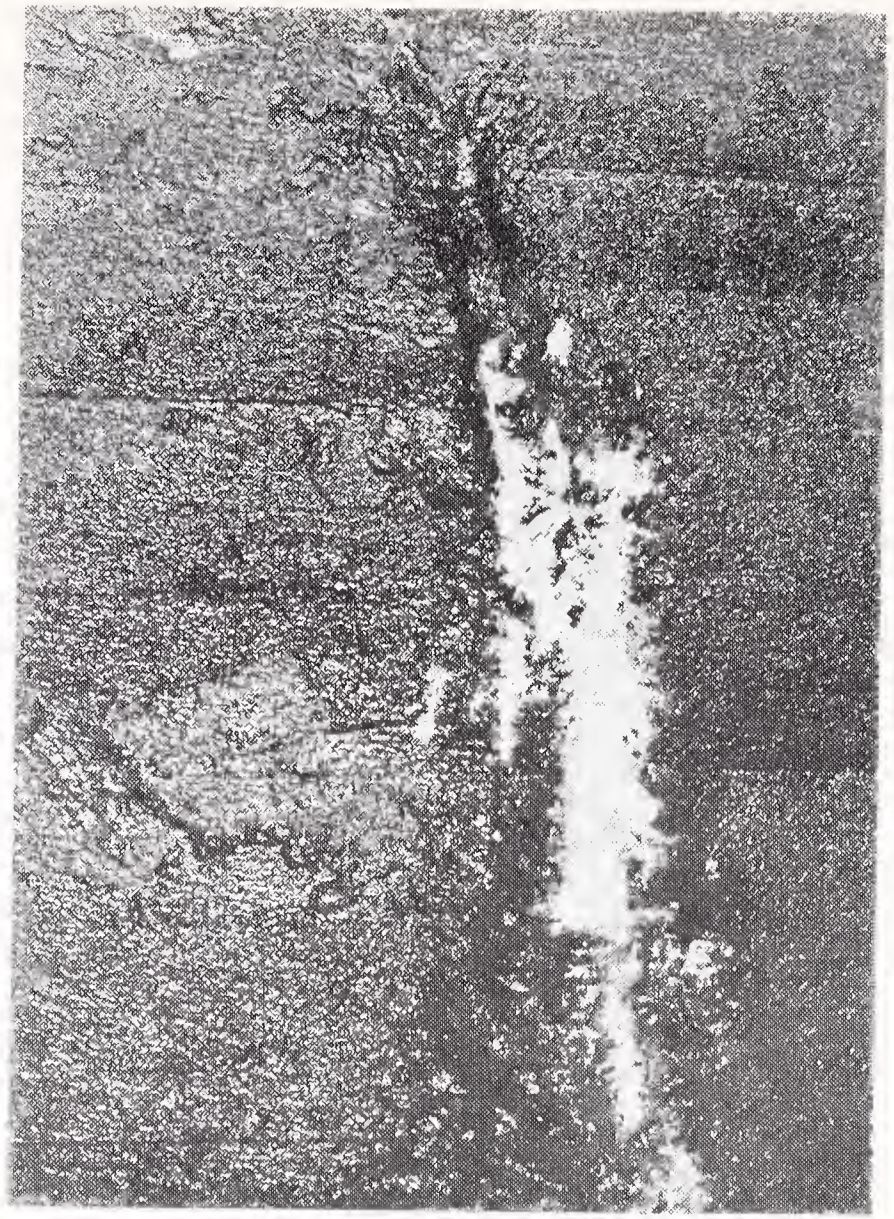


Photo 6 Calcium buildup at cracks on tunnel liner

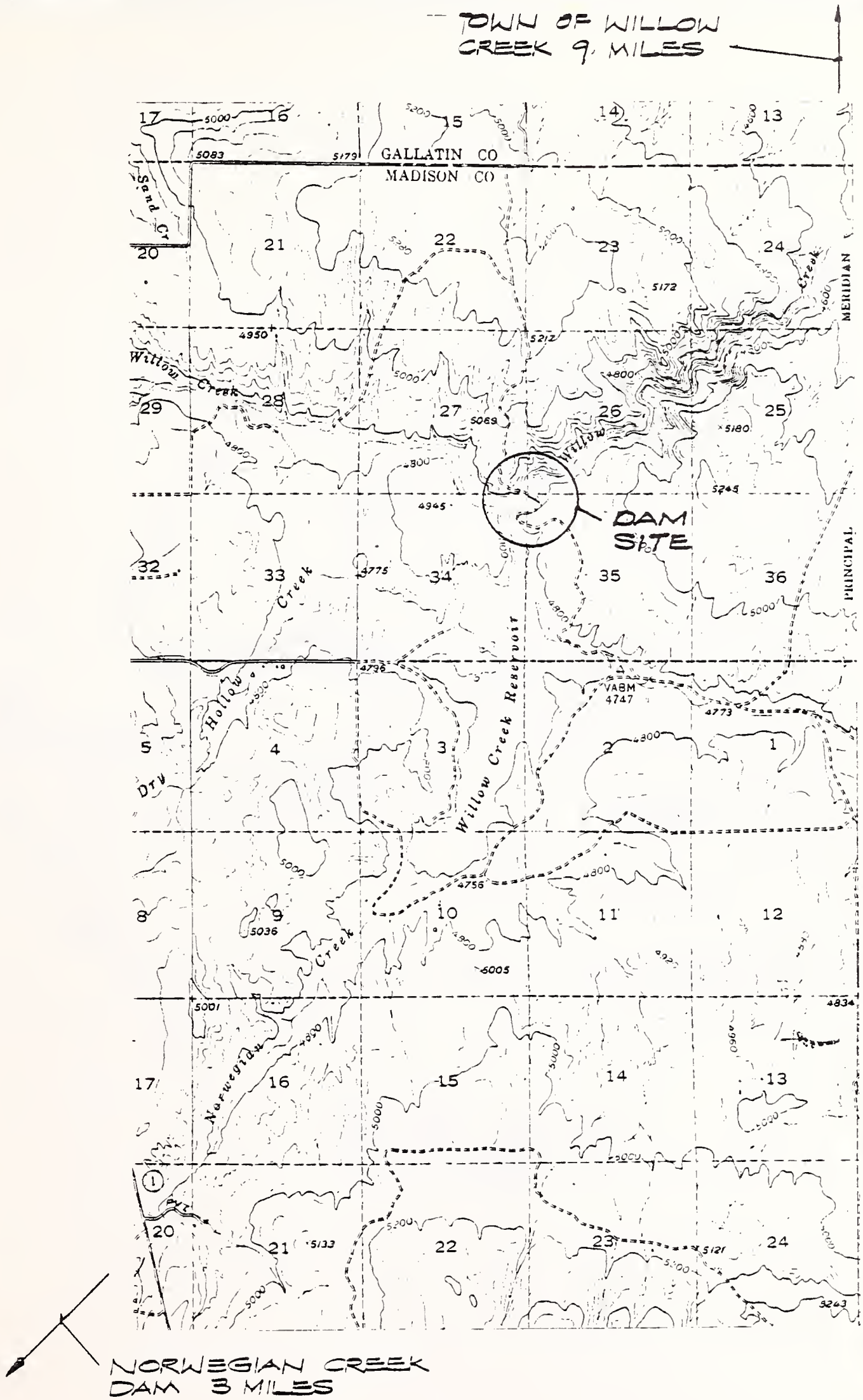
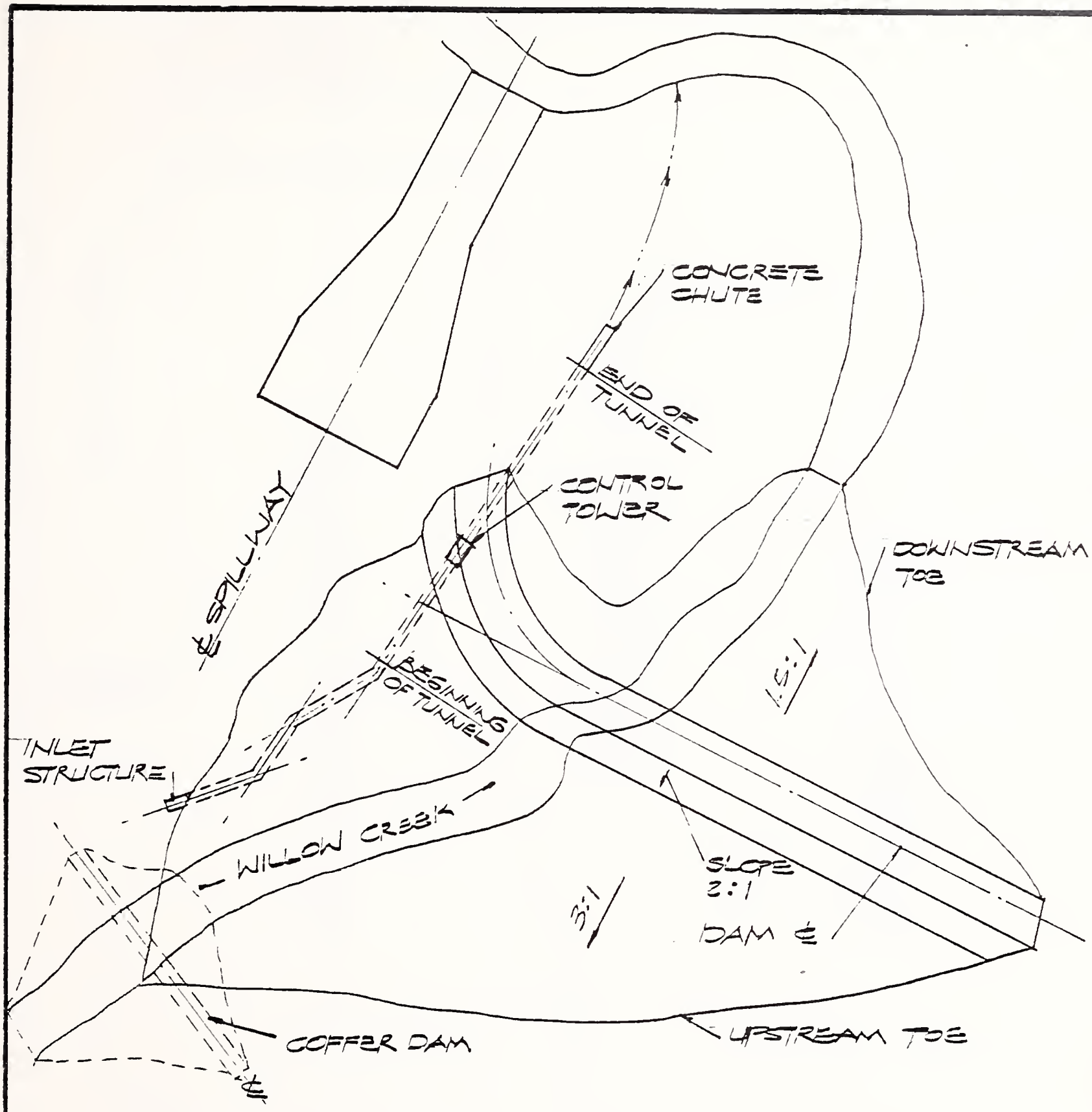


PLATE 1

WILLOW CREEK DAM VICINITY MAP

CH2M HILL



SITE PLAN

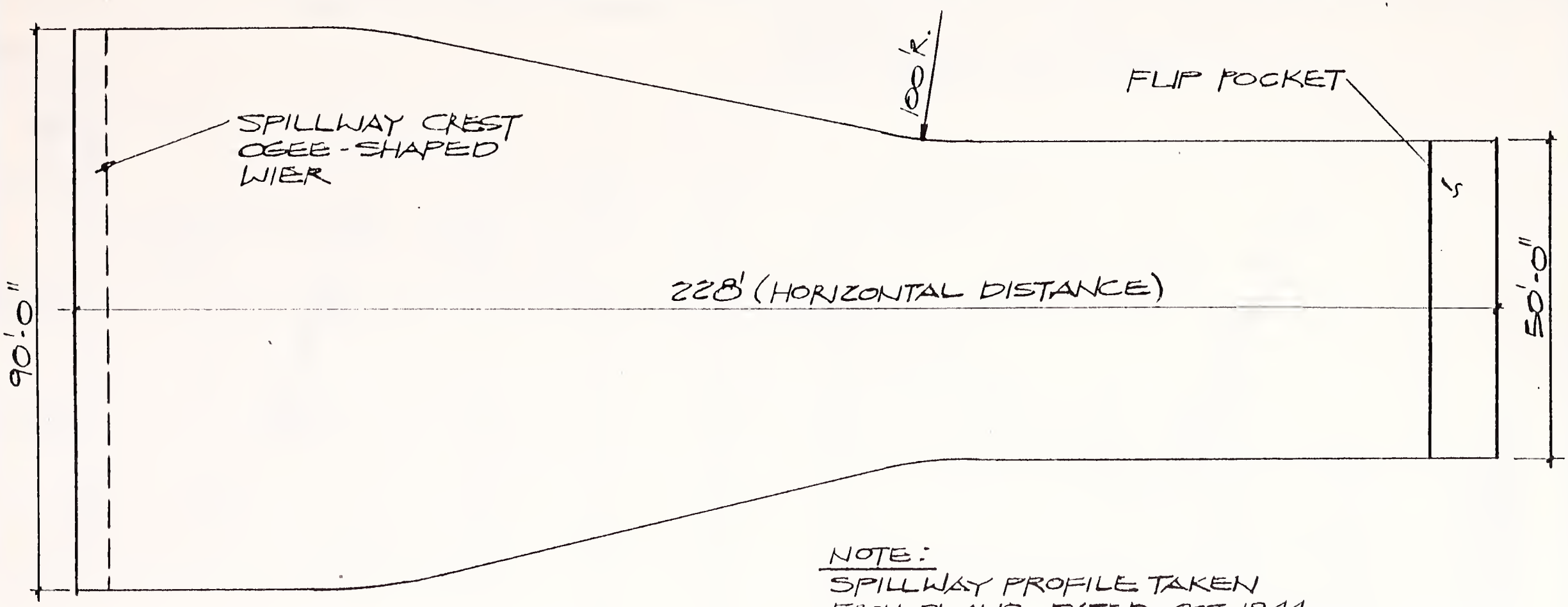
N.T.S.

PLATE 2

WILLOW CREEK DAM

SITE PLAN

CH2M HILL

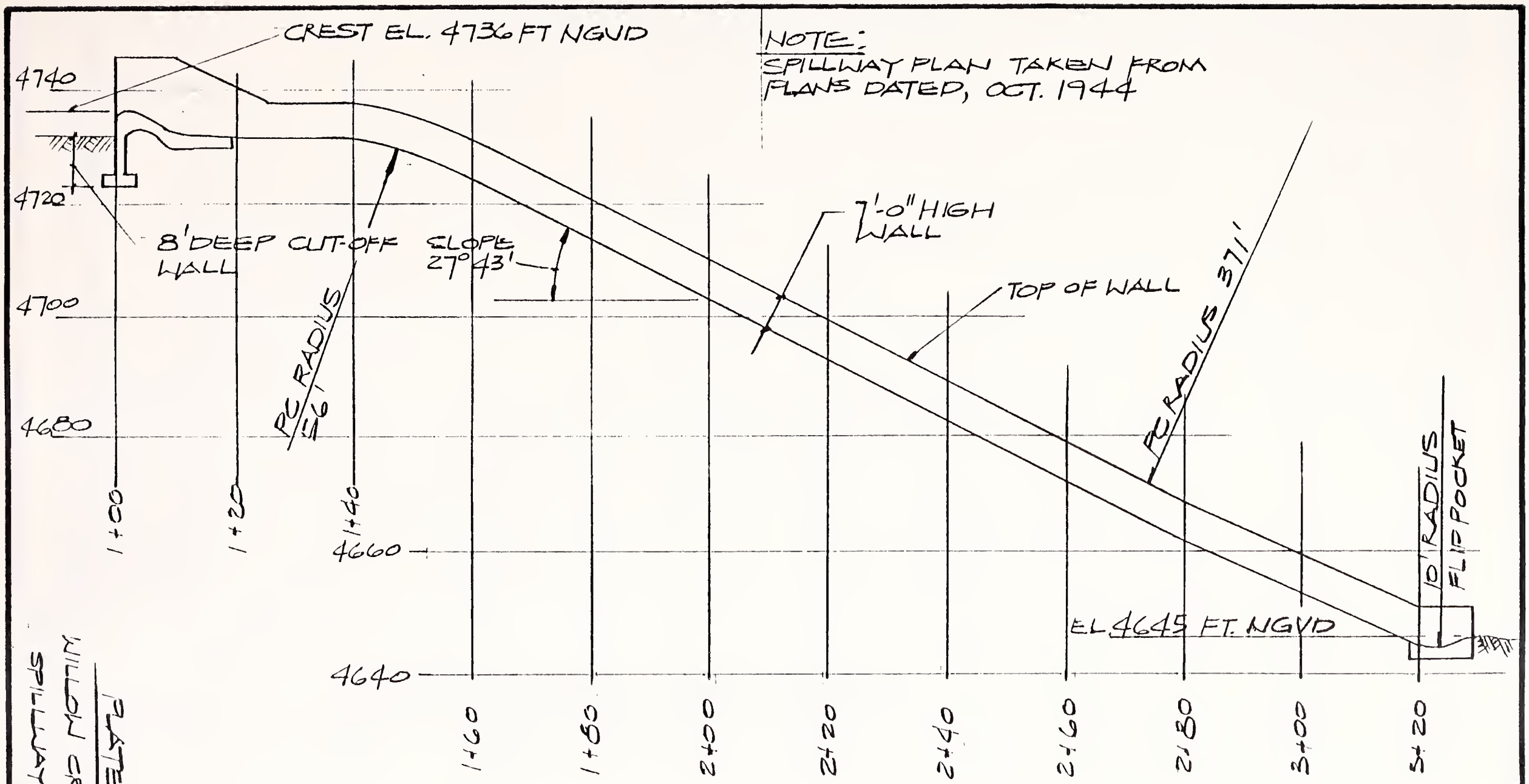


NOTE:
SPILLWAY PROFILE TAKEN
FROM PLANS DATED, OCT. 1944

SPILLWAY PLAN
3/8" = 10'-0"

PLATE 3
WILLOW CREEK DAM
SPILLWAY PLAN

CH2M HILL



SPILLWAY PROFILE

3/8" = 10'-0"

PLATE 4

WILLOW CREEK DAM

SPILLWAY PROFILE

CH2M HILL

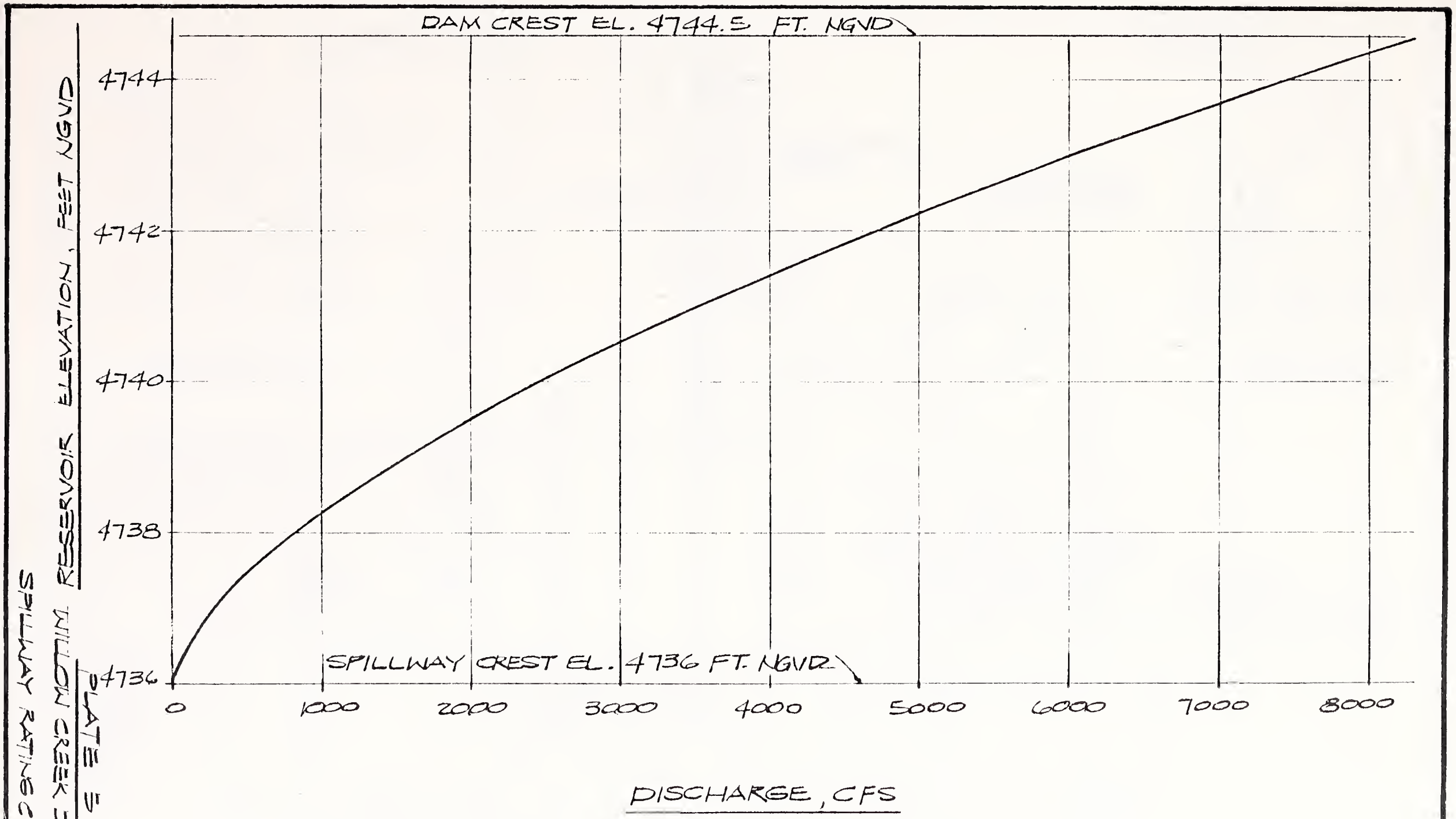
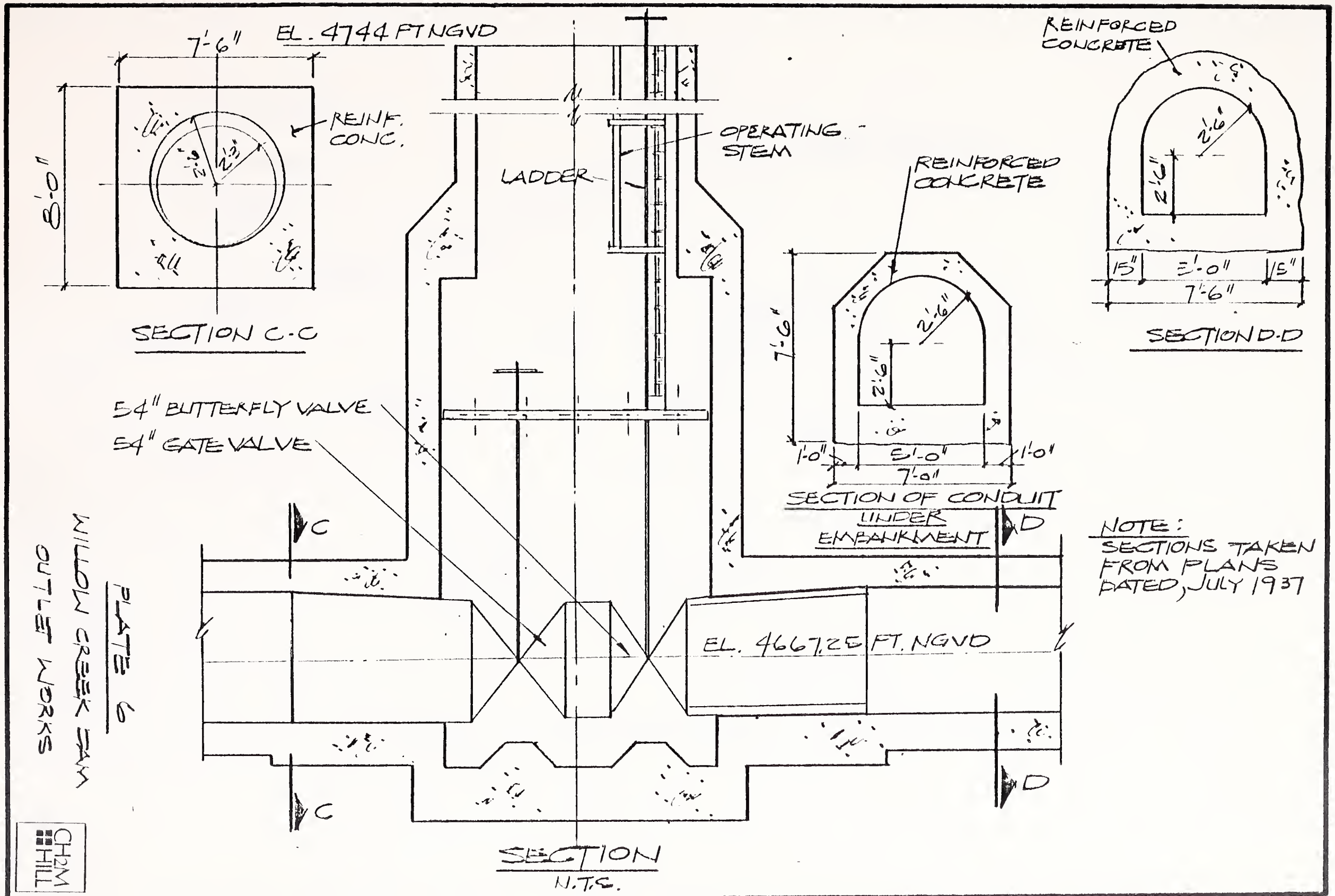


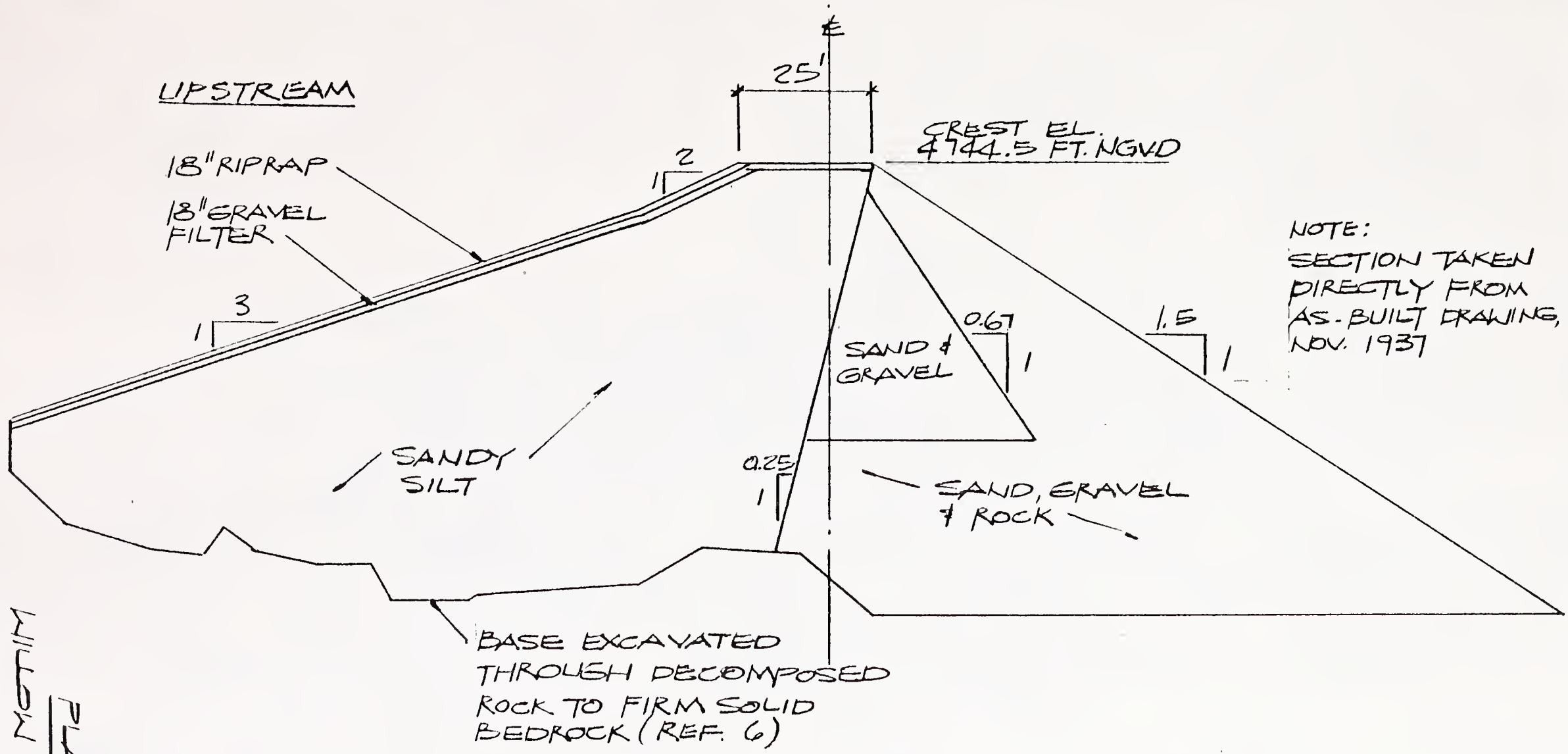
PLATE 3

WILLOW CREEK DAM

SPILLWAY RATING CURVE

CH2M HILL


EL. 4744 FT NGVD
7'-6"
8'-0"
REINF. CONC.
2'-3"
SECTION C-C
OPERATING STEM
LADDER
REINFORCED CONCRETE
2'-6"
2'-6"
7'-6"
1'-0"
5'-0"
1'-0"
7'-0"
SECTION OF CONDUIT UNDER EMBANKMENT
REINFORCED CONCRETE
2'-6"
2'-6"
15"
3'-0"
15"
7'-6"
SECTION D-D
54" BUTTERFLY VALVE
54" GATE VALVE
C
C
D
D
EL. 4667.25 FT. NGVD
SECTION
N.T.S.
NOTE:
SECTIONS TAKEN FROM PLANS DATED, JULY 1937
PLATE 6
WILLOW CREEK DAM
OUTLET WORKS
CH2M HILL



NOTE:
SECTION TAKEN DIRECTLY FROM AS-BUILT DRAWING, NOV. 1937

DAM EMBANKMENT SECTION

1" = 30'

PLATE 7
WILLOW CREEK DAM
DAM EMBANKMENT SECTION

CH2M HILL